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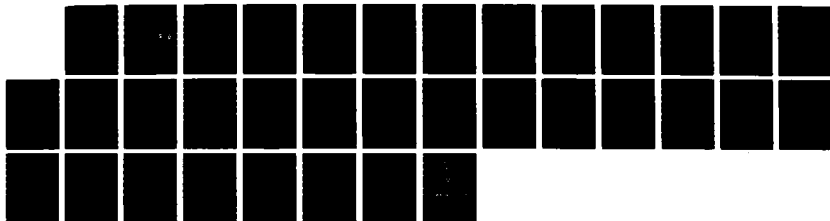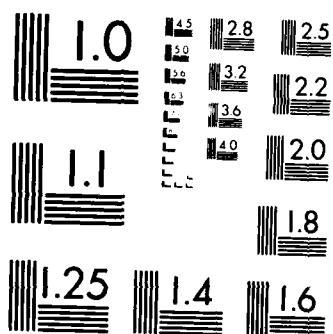
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Construction Engineering
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AD-A188 134

Evaluation of Building Design/Analysis Software for Microcomputers

by
William Bahnfleth
Dale Herron
Karen Ruby

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This report documents the results of an evaluation of microcomputer-based programs for building energy analysis and heating, ventilating, and air-conditioning system designs. The programs were evaluated for ease of use and calculation performance.

The study showed that all programs evaluated were suitable for use by building designers and that no program package could be identified as clearly the best. Each program has a unique set of strengths and weaknesses.

Load-estimating and duct-sizing software packages were tested by simple design problems. Load-estimating software performed consistently, although differences in algorithms resulted in clear discrepancies among cooling load predictions. Duct design programs did not agree particularly well, especially with respect to pressure drop calculations. Further performance evaluations are necessary. Information in this report should help designers select the program packages appropriate for their experience level and design application.

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CONTENTS

EVALUATION OF BUILDING DESIGN/ANALYSIS SOFTWARE FOR MICROCOMPUTERS

1 INTRODUCTION

Background

During the past decade, the U. S. Army Corps of Engineers has upgraded its design guidance to produce more energy-efficient facility designs. The improved guidance has tightened prescriptive standards, implemented design energy budgets for each facility, and required rigorous energy evaluations to be performed for new facility designs. Thus, the Corps designer's need for affordable, easy-to-use computerized building design/ analysis tools has grown tremendously.

Historically, Corps designers have used mainframe computer-based energy analysis programs such as the Building Loads Analysis and System Thermodynamics (BLAST) program[1] for all their facility energy analysis requirements. The recent development of affordable microcomputer technology has greatly increased building design/analysis software for microcomputers. Designers may now choose from a large number of software packages for load/energy analysis, duct and piping calculations, equipment sizing and selection, and economic studies.

Many of these recently developed programs may be suitable for use in Corps design studies. Most of these programs are relatively new to the field, fairly expensive to acquire, and make similar claims regarding their ease of use and performance; therefore, there is a clear need for independent evaluation and comparison of similar programs to help Corps designers determine what software is most suitable for their design studies.

Objective

The objective of this study was to evaluate the performance and the ease of use of a representative selection of currently available microcomputer-based load/energy analysis and duct-sizing programs, focusing on user-oriented features of input, output, documentation, and support. Results of this evaluation should be used to propose a course of action for potential users of the programs.

Approach

Corps of Engineers designers and software catalogs were surveyed to determine the programs to be evaluated, and arrangements were made to obtain demonstrations or actual versions of the software to be tested. Each program was evaluated for ease of use for input, output, documentation, and training. The performance of each program was then evaluated by conducting an example typical analysis and comparing the results to those produced by similar programs.

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[1]D. C. Hittle, *Building Loads Analysis and System Thermodynamics (BLAST), Program Version 2.0, Volumes I and II*, Technical Report E-153/ADA072272 and ADA072273 (U. S. Army Construction Engineering Research Laboratory, 1979).

Scope

A ranking or recommendation of the software considered in this report is not intended, nor should it be inferred. The limited comparisons of computations made during the study are not sufficient to support a performance ranking.

Mode of Technology Transfer

It is recommended that the information in this report be summarized in an Engineering Improvement Recommendation System (EIRS) Bulletin.

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2 PROGRAM SELECTION AND EVALUATION METHODOLOGY

Program Selection

Only programs currently used by the design community were selected for this study. Personnel in Corps District offices were interviewed to learn about their design practices, and software catalogs were searched to locate mechanical system design programs. A software search company was employed to obtain demonstration (if available) or full-scale versions of programs identified as being suitable for Corps use.

The programs selected for review were:

1. Carrier--E20-II
2. Trane--CDS
3. Elite--heating, ventilating, and air-conditioning (HVAC), Duct Sizing (demo versions)
4. Morgan Systems-Trakload (demo version)
5. APEC--Superduct II
6. MC2--Commercial Cooling and Heating, Duct Sizing.

McQuay Corporation's equipment sizing programs are also discussed, although the package was not obtained and run.

Evaluation Methodology

The elements considered most important in a mechanical system design program were ease of use and performance. A program's ease of use depends on its software and the user's experience. A program written for a beginning user with little computer-related experience may be easy for him/her to use, but too time-consuming for an experienced user. Ease-of-use features evaluated for the program packages were:

1. Data input procedure
2. Available program outputs
3. Program documentation
4. Customer support and training.

These factors were evaluated in terms of their suitability to both beginning and experienced users.

Performance features evaluated were:

1. Heating, cooling, and total building loads from loads analysis programs for a small sample building.

2. Duct sizes, air velocities, and pressure for both static regain and equal friction sizing methods from duct programs for a small duct system.

Loads analysis and duct design programs were selected for performance evaluation because designers commonly use them and because they are available in most program packages.

Attention was devoted primarily to the programs' ease of use. Calculation results were compared only to ensure that the programs were technically comparable rather than to validate the algorithms used.

3 PROGRAM EASE OF USE—EVALUATION RESULTS

This chapter describes user-oriented features of the software packages considered. Purchase and licensing costs, hardware requirements, and algorithms are also discussed. Table 1 summarizes ease of-use, support, cost, and hardware requirements in matrix form.

Carrier E20-II

Carrier Corporation was an early competitor in the microcomputer HVAC software market. Its E20-II series, which was first marketed in mid-1980, ran on Radio Shack's TRS-80 computers. Microcomputer technology has advanced greatly since then, and Carrier software improvements have kept pace. Current versions of E20-II will run on IBM or compatible, Tandy, and Radio Shack microcomputers (although support of Radio Shack machines is to be phased out).

The E20-II series is a complete line of mechanical system design software. All programs are stand-alone and written for microcomputers. At the time of this comparison, the package included:

- Commercial Load Estimating
- Residential Load Estimating
- Operating Cost Analysis
- Duct Design
- Piping
- Equipment Selection
- Life-Cycle Cost Analysis.

(The most recent version of E20-II does not contain the residential programs.) The programs are intended for use by mechanical engineers, and range from somewhat difficult to use to user-friendly, interactive software, depending on when the last program revision occurred. Recently updated programs include Equipment Selection V2.5, which was completed in the fall of 1984, and Operating Cost V2.0, released during the summer of 1985. Duct and Piping V2.0 and a new hourly energy analysis program, HAP, were released in 1986. Carrier has made the more recent updates so user-friendly that a technician can use them with relative ease.

The E20-II package consists of five binders containing the user manuals and diskettes. Carrier provides a hardware operation manual that discusses basics such as disk backup procedures. This manual is very handy for first-time computer users, or for those who do not have other applications for their personal computer (PC).

Updated user manuals typically accompany program revisions. Recent manuals are considerably more useful than their predecessors. The new documentation is organized to correspond with the program's main menu. Diagrams clearly show the path the program takes for all menu choices. The manual is excellent for the first-time user and works well as a reference for those with more experience. In most cases, an example problem is provided, and program input forms are furnished. Each manual has a documentation chapter that clearly references and describes algorithms and data used in the program.

Table 1

Summary of Software Characteristics

Vendor	Software	Purchase and License Costs	Hardware Requirements	Updates	Documentation	Input	Output	Training	Support
Arthur	TRH-R Mech. design package	License $595; Renewal $270 yr.	IBM PS-2, or compatible; Tandy 1000, 3000. HP VECTRA; Radio Shack (to be phased out);	Shipped, cost covered by license	Updated manuals very good, older manuals fair	Forms provided; menu-driven; full screen edit; displays defaults	Clear, complete	Training for 1 person included in annual fee; additional persons $225 each	Local representatives; no charge
Byte	CDS Mech. design package	License $1200; Renewal $500 yr.	IBM or compatible	Shipped or download via communications package. Cost covered by license	Copious, generally good	Forms provided; editing software; outline help	Cramped format; "Rule of thumb checks" are helpful	Regional seminars $350 to $1000 depending on topic, location	Mailed bulletins, electronic mail, and bulletin board. Phone support; no charge
Thin	Individually marketed mech. design programs	Ranges from $595 to $1145	CP/M and MS-DOS machines	Charge for enhancements	Concise, organized according to program menus	Forms provided; menu-driven online help	Double-heading tables are hard to read; otherwise good	None	Informal phone support; no charge
Morgan	Frei-load Energy analysis and HVAC sizing program	Engineering Version $795; Energy Audit System $1195	IBM PS-2, PC, or compatible	Charge for enhancements ($50 to $100)	Clear, includes brief descriptions for experienced users	Straightforward, defaults can be displayed	Basic reports lack detail. Optional output enhancement can be purchased	None	30 days free; thereafter, 4 hr for $250 + $100 for tie in to electronic bulletin board
Afro	Superduct II duct design program	$995	IBM or compatible	Charge for enhancements	Very complete	Forms provided; input processor menu format	Thorough; warnings given for inappropriate fittings	None	Small problems by phone at no charge; technical consultation for fee
Aro	Individual and group packaged mech. design programs	Commercial A/C group: $1745; HVAC energy consumption: $995	CP/M and MS-DOS machines	Enhancements for $30 + price increments	Older manuals concise (possibly too much so). Newer manuals more detailed	Forms provided; menus (help included in recent updates)	Well formatted, reasonably complete	Informal—at their Miami, FL, site	Phone support; no charge

User manuals for programs that have not yet been revised from the original are not as easy to follow. They work fairly well for a first-time user who is willing to read through them, but they do not easily function as a reference source when problems arise.

The most recent version of the Commercial Loads program sets the standard for future Carrier releases. It is entirely menu-driven and employs a full-screen edit format that uses all four cursor keys. The bottom of the screen displays the range of values and the default for the current input. It is very easy to scan through the input file to check for and correct errors, and to page forward or backward through the screens.

The program is flexible and allows a fairly sophisticated building description. Up to eight different exposures can be used in one space. Several wall, roof, window, and shading types can be described. Zone descriptions are simple; a minimum amount of system information is required. Each zone may contain up to 50 unique spaces, each with a multiplier of 1 to 50. Zone loads are calculated individually and the peak sum is reported as the building load.

Carrier uses ASHRAE* weather data for 434 cities; these data can be altered to reflect local conditions more accurately. Load calculations are done by the *Carrier Design Manual* procedure.

The Commercial Loads Program will calculate the loads for 10 different solar times as chosen by the user; it also will perform a 288-hr annual calculation (12 months, one 24-hr day per month). The maximum load time is the time used for the detailed single-hour calculations.

Single-hour output includes detailed zone loads, space cooling and heating load airflows, zone loads and system information summaries, transmission and solar gain calculation results, coil selection parameters, heating and load calculation results, and peak space loads for the zone. All output reports are clear and easy to read.

The Duct Design program was last updated in 1981. The program can use either the equal friction or static regain sizing methods. Outputs are the same for both methods and include size of ducts and runouts, velocity, static and total losses, static and total pressure, and bill of materials. This program does not do head loss and noise calculations.

The manual is clear and steps through the program logically. Input forms are provided, although they have not been organized to reflect the order of input requested by the program. The program also requests input that is not listed on the form. Input of duct design data can be tedious. Carrier has somewhat alleviated this problem by including a feature that sets the default to the last value input. This is particularly helpful with large systems. Up to 200 ductwork sections can be input in a single system. A library of 10 common fittings and eight elbows with their associated loss coefficients is included. The data may be saved for revisions.

Carrier markets a comprehensive line of equipment selection programs. Very few inputs are required for any one selection program, and they can usually be obtained from previous outputs. However, the user must have a fairly good idea of what equipment types are appropriate. It should also be noted that these programs select Carrier equipment.

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*American Society for Heating, Refrigeration, and Air-Conditioning Engineers.

The program selects chilled water, hot water, and DX coils in accordance with ARI Standard 410.[2] Fan selection is in accordance with ARI Standard 430-74.[3] Both the chilled and hot water programs display all coils that can fit specified conditions, while the DX program, using Refrigerant 22, will select a single coil. The Carrier DX Split System Component Selection Method is used to select the condensing unit, distributor nozzles and expansion valves.

Carrier packaged units between 3 and 200 tons can be specified using the selection and performance programs covering vertical, rooftop, air-cooled packaged chillers, split condenser chillers, and water-cooled chillers. Carrier also offers an operating cost analysis program, a piping program, and a life-cycle cost program.

The E20-II package can be licensed for $985,* which includes a basic training course for one person. More people can be trained for $225 each. Training is held in various major cities. The annual license renewal fee is $250, and includes update training. Carrier's local representatives are responsible for answering any questions about the software and its use. Updates are mailed to license holders as ongoing support.

Together, these programs make up a comprehensive HVAC design package. Carrier has combined the technology of microcomputers with its considerable experience in writing software to create a series of menu-driven, user-friendly programs with readable documentation and clear output reports. The result is a very appealing and usable product.

Trane-CDS

Trane's Customer Direct Service (CDS) network package covers the entire range of mechanical system design. Stand-alone micro programs include:

- TRACE Load Design
- Equal Friction Duct Design
- Varitrane Static Regain Duct Design
- Hot Water, Chilled Water, and Refrigerant Coil Selection
- Air-Handling Unit Selection
- Fan Selection
- TRACE Economics.

The CDS package also provides a program that allows the user to communicate with Trane's host computer in LaCrosse, WI. Input can be prepared on the microcomputer and submitted electronically for Trane's mainframe programs: TRACE Load Design, TRACE Load Estimating, Varitrane Static Regain Duct Design, TRACE-II, and TRACE. (Trane expects to release a PC version of TRACE in 1988.)

The communication package is also used to access Trane's electronic mail system that sends and receives messages and program updates. The communications line can be used to request assistance with problems.

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[2]ARI Standard 410, *Standard for Forced-Circulation Air-Loading and Air-Heating Coils* (Air Conditioning and Refrigeration Institute [ARI], 1981).
[3]ARI Standard 430-74, *Standard for Central-Station Air-Handling Units* (ARI, 1974).
*Prices cited in this report were current as of November 1987.

CDS programs will run on IBM or compatible microcomputers. The communications program needs a Bell 212 or compatible modem.

The stand-alone loads program can handle up to 150 zones and is quite flexible in its envelope description capabilities. Twenty-four types of systems can be simulated, although only one system, with the addition of a skin system, can be modeled in each run.

The program is based on the TRACE mainframe program. Load calculations are done in accordance with algorithms and weather data found in the 1981 *ASHRAE Handbook of Fundamentals*. Output is presented in tabular format. Although concise, the abbreviated table headings are not easy to read. Output includes cooling block, peak zone, and detailed internal loads; heating detailed internal loads; and air requirements, design values, and psychrometrics. There is also a convenient "Rule of Thumb Checks" box that lists cooling tons, heating Btu/sq ft, and supply cu ft/min (CFM).

Two duct design programs come with CDS: (1) Varitrane, a Variable Air Volume (VAV) duct design program that uses the static regain method and (2) an equal friction program, which is a computerized version of the Trane Ductulator.

The equal friction program is similar to other duct design programs. It provides a library of seven standard takeoffs and seven elbows. ASHRAE algorithms are used for all fittings and duct sizing. The program will allow at least 200 trunks and 400 sections. The output contains:

- Size of ducts and runouts
- Friction, fitting, and other losses
- Velocity
- Bill of material.

The Varitrane program differs greatly from other static regain duct design programs. An *Applications Engineering Manual* includes details about designing ductwork for VAV systems. Varitrane program calculations are based on ASHRAE algorithms and data, but also include Trane's own design factors. Heat and sound calculations are provided; the calculations consider the type of terminal unit. The program restricts the shape of ductwork to round. Varitrane permits up to 80 trunk ducts and 120 runouts. The output contains:

- Size of trunks and runouts
- Static pressure everywhere in the system
- Total pressure
- Type of fitting
- Bill of material
- Where insulation is needed
- CFM after duct heat pickup
- Decibels of fan sound to be removed by fan absorber
- Size of terminal units, corrected air quantity, and sound level at outlets.

The Varitrane program is the most comprehensive static regain program reviewed, but is also easy to use. CDS has a complete line of equipment selection software. Equipment covered includes chilled water, refrigerant, and hot water coils. All coil selections are in accordance with ARI Standard 410-72.[5]

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[5]ARI Standard 410-87, *Forced Circulation Air-Cooling and Air-Heating Coils* (ARI, 1987).

In addition, Trane Central Station air-handling units have a selection program. Trane centrifugal, utility, Model Q, and Varifax fans can be optimized, and a large commercial rooftop selection program is provided. Trane has also developed a fan system simulation program, FANMOD, which calculates operating and life-cycle costs for the fan system.

Trane's approach to the design process, including program inputs and output reports, is sophisticated. Newcomers to the design field may feel uncomfortable with it, while the experienced engineer will find it a timesaver. In some cases, the ability to make appropriate input choices depends greatly on the user's experience. Defaults are not necessarily provided.

Trane provides input forms for all its programs. The input method is the same for all programs, with the format following that of the Trace Energy Analysis input. With Trane programs, the engineer prepares the form, and a clerk does the actual keyboard input.

Trane input has two features that can greatly simplify and speed up the input process:

1. VEDIT--a word processor-type editor that allows a clerk to prepare and modify any input file quickly.

2. EDIT--an input file checking procedure that identifies inputs that are missing or out of range.

For those who share computers or prefer desk work to visual display terminal (VDT) input, this input process makes efficient use of the PC's time.

On-line help is not provided, but is not missed since the emphasis is not on computer-time input. The EDIT option will print the input file and list of errors found. The error messages are very explicit; this makes it easy for the user to discover his/her mistake.

Documentation for the programs is extensive and well organized. CDS arrives in six binders: a *TRACE User's Manual*, *TRACE Documentation*, *Design User's Manual* covering the micro Load and Duct Design programs, *Selection User's Manual* for the various equipment selection programs, an *Operator Manual* discussing fundamental CDS procedures, and a binder for the master diskettes.

The user manual (frequently, an Engineering Bulletin replaces the user manual) describes each input in order of occurrence. Whenever possible, a range of values that the input may take is provided.

The CDS package, including the communications program, can be licensed for $1290. There is an annual renewal fee of $390. Points (computer use credits) that can be applied to use of Trane's mainframe programs can be purchased with the CDS package.

Customer support is readily available from the CDS Network Support Center either by telephone or electronic mail, so the user can be confident of getting continued support and program updates. Regional training seminars on various topics are offered for $350 to $1000. The price depends on the topic, length of course, and location.

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Trane-CDS is a very functional software system. Its best features are the uniformity and ease of input among all programs, the EDIT option and extensive error checking, the speed with which a job can be input and run, and the communications package that provides an immediate link for accessing micro updates of the mainframe programs.

Elite

Elite Software Development, Inc., has several mechanical system design programs:

- Commercial HVAC Loads
- Building Energy Analysis
- Residential HVAC Loads
- Duct Sizing
- Hydraulic Pipe Sizing.

Other programs Elite offers for building design include Glass Shading Analysis, Lighting, Short Circuit, Fire Sprinkler Design, U-Factor Calculations, and Life-Cycle Economics. Elite Software is easy to use, consistent among programs, and adheres strictly to industry standards. The programs are intended for use by the mechanical engineer or architect with previous design experience.

All Elite programs require a CP/M, CP/M-86, or MS-DOS operating system. Memory requirements vary among programs, and are not excessive. Versions are available for one- or two-disk-drive PCs. A wide selection of disk formats is offered.

The HVAC and Energy Analysis programs use ASHRAE-recommended cooling load temperature difference (CLTD) data and calculation procedures. The program will do hourly calculations for up to six design days. Envelope capabilities are sufficient to describe any typical commercial building. Shading devices may be specified; however, unusual design features are not easily accommodated. The number of zones allowable is determined by the version of the program purchased.

The HVAC program can have up to 100 air systems. A system can be defined as either packaged or chilled water and, depending on the choice, a number of inputs are requested. This program offers some unusual input options; for example, leaving coil saturation can be specified as opposed to leaving coil air temperature, and the user can select from among three methods for handling exhaust air.

All program input is menu-driven and interactive. Default values are provided whenever reasonable, and the user can reset these values in a Master Data file. Exceptions to the defaults are accommodated in secondary data files.

User inputs are checked before the program switches to the next menu; any errors are marked for immediate correction. On-line help is provided for all inputs. Unfortunately, the text of the help is identical to the text in the user manual.

The program will run after input is complete and will print results automatically. The output reports reflect all inputs. The HVAC program output lists detailed zone load calculations, systems zone summary and total load summary, psychrometrics, and total building loads summary. Although complete, the reports tend to be difficult to read. Several tables are crowded onto one page, and important information does not stand out.

Elite offers two duct-sizing programs: equal friction and static regain. The programs follow ASHRAE-recommended procedures. The static regain program calculates sizes using the static regain, equal friction, or constant velocity method. The equal friction version does not include the static regain method. The two programs are *otherwise identical.* More than one sizing method can be used in a single system. Overall, the Elite duct-sizing programs are very flexible and can accommodate large, complex systems. At least 100 trunks and runouts can be sized. The programs will size round or rectangular ducts. The program is easy to use and input proceeds quickly.

Elite does not provide a library of common elbows; the user must look up his/her own loss coefficients. "T" and "Y" fitting loss coefficients are taken from 1981 *ASHRAE Fundamentals.* The program will do heat loss calculations. The output contains:

- Echo of input
- Size of trunks and runouts
- All losses at all points in system
- Velocity and CFM of flow
- CFM after heat gain
- Static regain
- Location and magnitude of maximum static pressure loss
- Bill of material, including fittings summary.

As in the HVAC and Energy Programs, the output of trunk and runout data is inconveniently formatted. A double-heading method is used to combine two tables into one. Both would be more readable if left separate.

Elite has no equipment selection/performance program yet. However, McQuay Air-Conditioning Division offers such software in conjunction with Elite. (See the section on McQuay.) Elite, along with MC2, is one of the few software houses surveyed that provides a selection of both load/energy analysis and electrical system calculation programs.

Program documentation is concise and easy to read. The manuals follow a uniform format from chapter to chapter within the individual programs, and from program to program. The manuals are readily usable as reference material, and it is easy for the user to locate answers to his/her questions. The chapters in the user manual are organized according to the menus in the program. Each input is described in order of appearance.

Input forms that can be photocopied are provided for the duct-sizing program. The HVAC and Energy Analysis programs have forms that have been used for example problems.

Although Elite has no formal customer support plan, the user can call the company with questions during business hours, and can often be referred directly to the programmer. Elite plans to continue this informal support. Training classes are not offered and are not thought to be necessary.

Elite programs are sold separately--an advantage for those who do not require an entire line of software. The commercial HVAC Loads program comes in four versions: 2, 50, 100, and unlimited zone capacity for the prices ranging from $295 to $1495. The Static Regain Duct-Sizing is $495, and the Equal Friction Duct-Sizing is $295. All programs have demonstration versions available for $35. The first cost for an equivalent

Elite package exceeds that of Carrier or Trane. However, Elite has no yearly license fee, and customer support is free.

Morgan Systems—Trakload

Morgan Systems Corporation produces Trakload--a Commercial Energy Analysis and HVAC Sizing program. Trakload is quite different from the other programs reviewed. A spreadsheet approach, coupled with an intelligent database, makes this program particularly easy to use. The objective of the program is to calculate design loads, airflow, cooling and heating equipment sizes, monthly and annual energy use, and operating costs. Several options are available that expand the program's capabilities:

- Energy Audit Option
- Weather Maker Module
- 8087 Math Co-Processor Overdrive
- Trakgraph Graphics Output.

A residential version of Trakload is also available.

Trakload will run on an IBM PS/2, PC, or compatible. The computer must have 256K of memory, two floppy disk drives, or one floppy and one hard disk drive. It requires MS-DOS version 2.0 or higher.

Trakload is directed at users with engineering and building system experience. It is useful for both designers of new systems and energy auditors of existing systems.

Trakload's user manual provides background information for those with no previous computer experience, as well as abbreviated instructions for practiced computer users. Inputs are discussed in the order they are encountered in the program. Sources for defaults are given and the algorithms used are referenced.

Loads are calculated using ASHRAE's modified bin method. The program will handle up to five zones and two systems in one building. Trakload comes with a selection of stored building input sets. The idea is to change existing data files rather than create new ones. The program will analyze office, apartment, store, restaurant, motel, warehouse, and school buildings. Envelope parameters are easy to change, but are not as flexible as in more traditional programs. For example, shading devices cannot be modeled in a straightforward manner. On the other hand, fairly complex systems can be handled easily. Trakload has a library of 14 systems and 12 types of cooling and heating plant equipment.

Data can be entered very quickly. The program makes good use of the IBM-PC keyboard: a function key will display a description of an input item, and another will display default values. Changing one input value will cause corresponding changes in associated parameters. For example, altering a wall description will cause recalculation of U-values and thermal masses, transmission loads, air quantities, and so on. This occurs by pressing a key rather than by running the program. In effect, the program runs continuously, and is truly interactive software. This makes Trakload very useful for analyzing different envelope and system configurations.

Design heating and cooling loads are displayed on the screen, but are not formalized into reports. This is also true for airflow, fan sizes, cooling and heating coil capacities, cooling, heating, and domestic hot water (DHW) equipment sizes.

After the envelope and system have been designed, the program takes a few minutes to calculate monthly and annual energy costs. There are detailed rate structures for two different fuel types. These data are compiled into one report consisting of yearly and monthly energy use in dollars and kWh or kBtu for all end uses. Loads are listed by zone and by system.

Trakload's Energy Audit option consists of 80 energy-saving techniques that can be applied to a building. This feature is particularly useful for retrofits.

The Weather Maker option will generate weather data files for locations besides the 10 cities furnished in Trakload. The 8087 Math Co-processor Overdrive option allows Trakload to use a computer's existing 8087 Co-processor. This can greatly cut calculation times.

Reporting capabilities can be increased by using the Trakgraph option, which was not reviewed in this study. It requires use of Lotus 1-2-3 or Symphony to format and create additional reports. Output can be displayed graphically.

Trakload is available in two versions: the "Engineering Version," which sells for $795, and the "Energy Audit System," available for $1485. Training can be obtained on a customized base either onsite or at Morgan Systems. The cost of training varies with the number to be trained and the type of training desired. Thirty days of free support are included in the initial cost of the program. Thereafter, consulting time can be purchased in 4-hr blocks at $250 per block. For an additional $100, the user can access an electronic communications system which facilitates both problem solving and downloading of program updates.

On the whole, Trakload is a very comprehensive program. It handles, very quickly and in one program, a range of tasks that some of the other packages require two or three programs to accomplish. Trakload is also very easy to use. However, it does not have the same flexibility of building descriptions as other programs. The reports produced by the basic Trakload package are not as detailed as those in other packages. However, the use of available options would remedy these drawbacks, and give it power, flexibility, and ease of use not found elsewhere.

APEC—Superduct II

APEC Incorporated (a nonprofit association of engineering firms) of Dayton, OH, produces and maintains Superduct II--a duct analysis and design program. Besides Superduct II, APEC has produced several other mainframe programs for building:

- HCC-II: hourly design heating and cooling load calculations
- ESP-II: energy program to simulate building operation
- HCCL-I: lower-level heating and cooling load calculations
- EDP-I: electrical distribution
- Piping: analysis and design
- OCP-I: overcurrent protection
- STD90: building envelope evaluation on microcomputers according to ASHRAE's Standard 90A-75.

Micro programs identical to the mainframe versions are available for HCC-III, EDP-I, STD90, and Superduct II and will run on IBM PS/2, PC, or compatibles.

Superduct II, Version 2, is the only APEC program considered in this review. The program will size ducts using constant velocity, equal friction, or static regain methods. Superduct II will accept presized ducts where required. It will also determine section and system losses, pressure losses, and fan requirements for a presized duct system. Within the system losses report, it will provide pressure loss data for orifices or damper settings required to balance a system. The program will size both supply and exhaust systems of up to 500 sections. Heat loss and sound calculations are not done. The only material that can be used is lined or unlined galvanized steel. Round, rectangular, or oval ducts can be specified.

The mainframe input process consists of preparing a file using the mainframe's line editor. The file uses an 80-column card format; all inputs must be precisely in their field for the program to run. The microcomputer version of the program has an input preprocessor that puts data into the proper format for the user. A new enhanced micro version of Superduct is completely menu-driven.

The user manual is very complete: it contains a description of the program, documentation of calculations used, a discussion of the engineering principles behind duct design, a large library of fittings and elbows, a thorough description of inputs including input forms, and a sample problem.

The output report provides:

- Warning messages for inappropriate fittings
- Section data:
  - Duct size
  - Velocity
  - Total and static pressure differential losses
  - Longest branch
  - Pressure loss analysis
  - Fan requirements
- Bill of material.

It is difficult to locate errors if the output does not appear to be correct. In most cases, however, the output is self-explanatory.

APEC mainframe programs are proprietary and can be accessed through Control Data's CYBERNET system by both APEC members and nonmembers. The microcomputer version of Superduct II is available to APEC members for a single payment of $995. Microcomputer programs are available only to APEC members.

Cost of telephone support service depends on the level of detail of the request. Program updates are offered at a nominal charge, both for mainframe and micro versions.

MC2

MC2 Engineering Software of Miami, FL, markets a wide variety of mechanical design programs, including:

- Commercial Cooling and Heating Loads
- Duct Design
- Heating Fuel Cost
- Life-Cycle Cost
- Residential Heating and Cooling (Manual "J")
- HVAC Energy Consumption System Simulation and Economic Analysis
- Solar Collector Sizing--F Chart
- Hydraulic Pipe Design
- Electrical Engineering Programs, Including Lighting Design and Fuse-Breaker-Wire Coordination
- Structural Engineering Programs
- Project Management
- Fire Sprinkler System Design.

The programs are sold both separately and in packages. The complete Commercial A/C Group costs $1745; the HVAC Energy Consumption program is $995. Enhancements are provided to current users at $30 each. If an enhancement has led to an increase in the price of a program, the user is charged the incremental increase. MC2 offers informal training in Miami at no charge. User questions are handled over the telephone by the programmer. "Bugs" will be fixed indefinitely.

MC2 programs will run on IBM or compatible machines. Many of MC2's programs come compiled. Those that run in interpreted BASIC are supplied with the interpreter on the disk. Both 8087 math coprocessor and RAM disk compatible versions are available. MC2 will supply programs on 8-, 5-1/4-, or 3-1/2-in. disks. If a user changes machines, MC2 will convert his/her software for $30 per disk.

CL4M was examined in this study. This program is based on the 1985 *ASHRAE Fundamentals, Carrier Handbook of Air-Conditioning*, and National Bureau of Standards (NBS) load programs. CL4M computes solar heat gain factors (SHGFs) directly from the recommended algorithms rather than by table interpolation. Wall classifications are determined on the basis of thermal lag coefficient by the program rather than by the user. Both of these features would be expected to contribute to an accurate calculation.

The program is menu-driven and interactive; input is fast and easy. However, making changes to existing files can be slow. All menus must be stepped through to access a single item to be changed. No on-line help is supplied, and very few default values are available. On-line help would be a welcome addition to this program, since the user manual spends very little time on inputs and the values they may take. (MC2 informs the authors that on-line help is a projected enhancement.) Defaults are not as important, however, since few zone inputs are defaultable. A user will build up his/her own library of construction elements, zones, and system, and compile buildings from these data.

Envelope descriptions in CL4M are flexible. Up to six wall exposures, three types of windows, three types of shading and two types of doors can be described per zone. Skylights can be modeled easily. A building can contain up to 255 zones, where 48 are distinct from one another. CL4M uses fewer system inputs than other programs. A total of 255 systems can be used, selecting from up to 24 typical systems.

The CL4M input procedure allows the user to replicate "typical" zones and systems. Typical zones also can be rotated or reflected by a simple procedure. This capability could save a great deal of time for the user.

The output includes cooling and heating design loads and supply air for each zone. Psychrometric calculation results for coil selection, cooling tons, and each zone load element are listed for the day of maximum cooling load. Building total loads are also reported. CL4M provides printouts detailing construction data, such as weight, area, U-value, and color of roof. This program can also print out necessary input forms.

The user's manual for the CL4M program is very concise. It provides a description of the program and its main menu, a short discussion of the required inputs, a summary of equations and procedures, several tables to aid the user with input, worksheets, and sample output. However, the user's manual has not been updated since 1980, aside from a 1982 addendum that describes some enhancements. Because this manual relies heavily on references to the 1977 *ASHRAE Fundamentals*, which few users would be likely to have, it is sometimes difficult to obtain a clear understanding of CL4M's input requirements.

MC2 offers another energy program--the HVAC Energy Consumption System Simulation. Although this program can be used for new construction, it is intended primarily for audits and retrofits of existing buildings. A variety of systems and central plants can be modeled. Loads are calculated by a modified bin method. Energy use and life-cycle costs will be calculated for a base case and compared with up to seven alternatives. Output includes annual and monthly energy consumption.

The DD4M Duct Design program was purchased for this study. MC2's program will size ductwork using any of the three common methods: equal friction, constant velocity, and static regain. It can handle round, rectangular, or oval ductwork. It does not provide for different material types. There is no library of elbows or fittings, and the user must supply all losses.

The program is totally interactive; each duct section is sized separately and requires the user's approval before the program goes on to the next section. No defaults are provided; if an entire duct system is made up of rectangular ductwork, the user must indicate "rectangular" for each section. When making changes in a section after completing a system, all data must be reentered, including fittings and losses, even if the only difference is CFM.

Output is very straightforward. Total pressure drops in all paths are compared, and a detailed description of each path is printed. This includes size, losses, velocity, total pressure, and pressure drop in the section. No bill of material is provided, and noise and heat loss calculations are not done.

The MC2 duct design is a modest program. Its interactive nature allows the user to know exactly what the duct system does and how changes in fittings will affect it. Although the program should be used by those with a mechanical design background, it could be educational for designers with little experience in sizing ducts. Overall, it is best suited to small applications.

(Note: the version of DD4M described in this report has been replaced by an enhanced, greatly improved edition. The newer version uses windows, has extensive help, runs interactively, and has a library of fittings [among many other changes]. This

development points to the limited life span of software comparisions. Because rapid change is the rule at present, potential users should always seek the state of the art.)

McQuay

McQuay Air-Conditioning Division of McQuay, Inc., produces several equipment selection programs available at no cost through McQuay representatives. This software--the MS-85 package--will run on CP/M or MS-DOS systems. The programs include:

- Heating and Cooling Selection
- Steam and DX Coil Selection
- Air-Handling Unit Selection
- Economic Analysis
- Specifications Library.

A fan coil selection program will be released soon.

McQuay offers, in association with Elite Software, a four-program package that includes the following Elite programs:

- Commercial HVAC Loads--50 Zone Version
- Building Energy Analysis
- Duct Sizing--Static Regain Version
- U-Factor Calculations.

The section on Elite Software Development, Inc. (pp 14-16) discusses these programs. This McQuay/Elite package costs $1250.

4 PROGRAM PERFORMANCE—EVALUATION RESULTS

Two problems were run on the mechanical system design programs. A simple building was modeled by the loads program, and a small duct system was simulated by the duct design programs. The intent was to compare results based on similar inputs to prove program equivalency--that is, to show that each program will do the calculations and achieve reasonable, comparable results. Verifying the accuracy of each program's calculations was not an objective.

Loads Performance Evaluation

The simple building used for the loads performance evaluation was a one-story, 9600-sq ft office building. The building was divided into an interior zone and one or two exterior zones, depending on the program's requirements. The HVAC system was multizone. All parameters, such as U-values, surface colors, square feet of glazing, shading, infiltration, thermal mass, lighting, occupancy, and use schedules were the same (to the extent possible) for all programs.

Uniform specification of infiltration proved to be the most difficult aspect of input. In the case of the Elite program, infiltration is an air-handling system input and may influence the ventilation air quantity calculated for the system. Infiltration is also a system input in the Trane program. Carrier's program sets the latent infiltration/ventilation load to zero during the heating load calculation. Intrinsic differences such as these virtually guarantee that significant variations in ventilation/infiltration load will occur between programs.

Further difficulties may arise from the diversity of units available for specifying infiltration. Carrier requires input in CFM. MC2 bases its calculation on an input value of CFM per square foot (SF) of roof and exterior wall area. Elite offers a choice of CFM/(SF of floor area), CFM/occupant, or air changes per hr (AC/HR). Trane will accept CFM, CFM/(SF of floor), CFM/occupant, AC/HR, or percentage of zone air.

A variety of methods is available for estimating infiltration in these many forms. Carrier recommends the use of the "crack length method" as found in its *System Design Manual*. MC2 refers the user to the "leakage area method" published in the *ASHRAE Handbook of Fundamentals*. Different methods will produce differing estimates of the total infiltration CFM, hence, the infiltration load. For comparison, it is best to work backward from the total CFM to determine the corresponding values of derivative input quantities required by various programs.

Table 2 summarizes sample load calculations by the Carrier, Trane, Elite, and MC2 programs. Also included for comparison are results of *ASHRAE Handbook of Fundamentals* calculations. These figures, generated as optional reports to the BLAST program, are representative of estimates that would be obtained by manual calculations. Agreement on heating load, the simpler calculation, was very good. The high and low estimates differed by 4.5 percent of the average. The Carrier infiltration figure is the only load component seriously at odds with the others. Since it was verified that the Carrier program does the same infiltration calculation as the others and that infiltration rates were all comparable, it is difficult to explain this discrepancy.

It should also be noted that the slab floor heating load is a potential problem source. While some programs use the perimeter loss coefficient method recommended

Table 2

Peak Heating and Cooling Loads for Test Building

Load	Carrier	Trane	Elite	MC2	ASHRAE Fundamentals
Heating (BTU/hr)					
Envelope:					
Roof	20448	19008	19008	19000	19008
Walls	22720	19346	17572	19300	19346
Glass	13121	12197	12196	12100	12197
Floor	24000	21384	21384	21800	22176
Ventilation	37488	34373	34214	34200	31034
Infiltration	22102	40102	41699	36400	29202
Peak	139879	146410	146073	142800	132963
Cooling (BTU/hr)					
Envelope:					
Roof	12341	9903	11637	8757	5898
Walls	6655	2961	4756	3610	6921
Glass	10892	24041	17159	16959	15991
Lighting	102390	81912	57288	68210	65104
Occupants	43200	48960	48960	41837	36456
Ventilation	16224	17699	15946	16274	18073
Infiltration	21550	18530	15946	17360	15814
Fan	6322	----	4531	----	----
Peak:					
BTU/hr	219573	204006	175817*	173006	164257
Tons	18.3	17.00	14.65	14.42	13.69
Cooling air	4800	4794	4992	5122	----

*Peak is not equal to the sum of components shown because output reported zone peaks at different hours.

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in the *ASHRAE Fundamentals*, others simply perform a UATD calculation defined as U x area (A) x temperature difference (TD), where U is the heat transfer coefficient. The perimeter method uses the outdoor ambient temperature whereas the UATD method requires an appropriate (and ill-defined) ground temperature.

Cooling load calculations displayed considerably more scatter than the heating load calculations. High and low load estimates differed by 24 percent of the average. Two major sources of this diversity can be identified. First, three different methodologies are represented in these programs. MC2 and Elite are conceptually similar to the currently recommended ASHRAE CLTD/cooling load factor (CLF) method. The Trane program calculates the loads using the older total equivalent temperature differential (TETD)/time averaging (TA) method. Carrier uses its own equivalent temperature difference method.

The second source of scatter is due to the complexity of the cooling load algorithm. Transient effects in envelope components, radiation through windows, and internal loads must be computed. The actual roof and walls of the user's building are generally matched to the closest available sections in the program's library. This arrangement inevitably leads to increased error.

The results in Table 2 show that the two CLTD related programs, Elite and MC2, agree quite well on a component-by-component basis. The Carrier and Trane results are likewise comparable, although there is less agreement on envelope loads. The lower values produced by Elite and MC2 are in line with what is known about the underlying algorithms. The CLTD method, because it accounts for mass effects in a more realistic way than the TETD method, generally gives results that are 20 to 30 percent lower.

The differences in lighting load between programs should be noted. The Trane value is precisely the rated lighting power (2.5 W/sq ft) expressed in BTU/hr. The Elite and MC2 numbers reflect an allowance for lag in the lighting load. The Carrier lighting load is the instantaneous lighting load (i.e., the Trane figure) multiplied by a ballast factor of 1.25, the program default for fluorescent lighting. The result of these differing approaches to a single load component calculation contributes 3.75 tons to the difference between the Carrier and Elite estimates. It is significant that Carrier gives 1.25 as a ballast factor default whereas the other programs use 1.0. The unthinking acceptance of defaults can lead to precisely the sort of phenomenon documented here. Users need to be acutely aware of default values and their implications.

The ASHRAE "manual" calculations predicted loads comparable to those estimated by the commercial programs. Both heating and cooling load estimates were lower than the lowest commercial estimate, but not by a significant amount. The heating load shortfall was due to a lower estimate of ventilation and infiltration loads. A lower occupant load accounted for most of the cooling load difference. The ASHRAE cooling load prediction compared most favorably with the Elite and MC2 estimates. This was to be expected, since the algorithms used in these two programs are most closely related to the ASHRAE CLTD/CLF method.

Duct Design Performance Evaluation

The simple duct system shown in Figure 1 was modeled using five or six trunk sections, depending on the program, and six runouts. The system was sized by five programs, using both equal friction and static regain methods--a total of 10 runs. Tables 3 and 4 present the results. The tables show the size of the duct, the velocity, and the pressure drop in that section.

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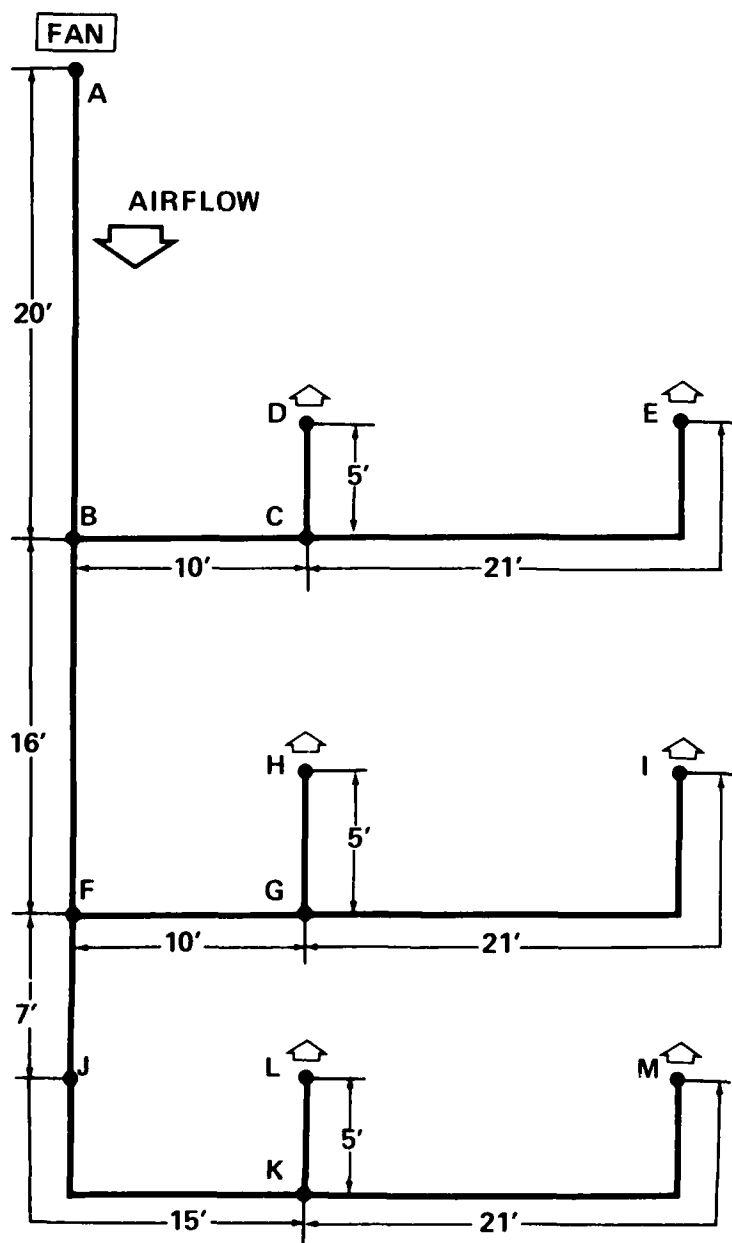
Figure 1. Test duct system layout.

Table 3

Results of Equal Friction Method Duct-Sizing Calculations

Duct Section	Carrier Size*	Carrier Vel**	Carrier ΔP***	Trane Size	Trane Vel	Trane WP	Elite Size	Elite Vel	Elite WP	APEC Size	APEC Vel	APEC WP	MC2 Size	MC2 Vel	MC2 WP
1	12 x 15	912	0.02	11	1500	0.09	14 x 14	929	0.02	13 x 14	901	0.03	12 x 15	974	0.03
2	11	758	0.06	9	1329	0.06	11	758	0.04	11	758	0.05	9	1132	0.16
3	11 x 11	762	0.02	9 x 9	1326	0.07	11 x 11	815	0.02	11 x 11	812	0.02	10 x 12	819	0.02
4	9	679	0.04	7	1178	0.06	9	679	0.03	9	679	0.06	8	859	0.10
5a	8 x 9	680	0.01	7 x 7	1144	0.04	8 x 8	770	0.04	8 x 8	815	0.01	9 x 9	725	0.01
5b		770	0.03	8	1212	0.08				9	770	0.03		770	0.03
6	9	679	0.14	8	986	0.19	9	679	0.02	7	1123	0.27	7	1122	0.19
7	8	573	0.12	7	895	0.33	8	573	0.02	6	1019	0.29	6	1019	0.24
8	8	573	0.14	7	896	0.17	8	573	0.02	6	1019	0.24	7	748	0.14
9	6	509	0.12	5	757	0.33	6	509	0.02	4	1146	0.39	5	733	0.16
10	8	573	0.15	7	896	0.17	8	573	0.02	6	1019	0.25	7	748	0.14
11	7	524	0.12	6	821	0.33	7	524	0.02	5	1027	0.30	6	713	0.14

*H x W or D in inches.
**Velocity in feet per minute.
***Inches of water.

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Table 4

Results of Static Regain Method Duct-Sizing Calculations

Duct Section	Carrier			Trane			Elite			APEC			MC2		
	Size*	Vel**	ΔP***	Size	Vel	WP	Size	Vel	WP	Size	Vel	WP	Size	Vel	WP
1	12 x 10	3110	0.24	18	1596	--	12 x 12	2812	0.17	14.3	2330	0.20	13	2812	0.17
2	12	1467	0.52	14	1137	--	9	2608	0.34	12	1467	0.43	9	2608	-0.34
3	9 x 9	2360	0.21	16	1150	--	9 x 9	2640	0.24	11	2182	0.11	12	2664	-0.33
4	10	1257	0.31	8	2117	--	7	2515	0.35	10	1232	0.37	10	2640	0.27
5a	7 x 7	2257	0.11	12	1104	--	6 x 6	2874	0.56	9	1738	0.17	10	2604	0.10
5b	8	2200	0.21			--									
6	9	1630	0.32	8	2174	--	7	2694	0.96	11	1091	0.35	7	2694	0.72
7	8	1238	0.27	8	1309	--	6	2200	0.35	9	978	0.22	6	2200	-0.78
8	8	1238	0.24	8	1358	--	6	2200	0.28	9	978	0.29	6	2200	-0.99
9	6	1212	0.32	6	1350	--	4	2750	0.79	7	898	0.21	4	2750	1.27
10	6	2200	0.61	8	1395	--	6	2200	0.37	9	978	0.39	6	2200	-0.87
11	7	1257	0.31	6	1935	--	5	2464	0.51	8	963	0.23	5	2464	0.17

*H x W or D in inches.
**Velocity in feet per minute.
***Inches of water.

Table 3 shows that Carrier, Elite, MC2, and Superduct II calculated the same, or nearly the same, duct sizes. Trane consistently predicted smaller trunk sizes. The largest runouts were selected by Carrier and Elite, followed by Trane, MC2, and APEC. There was sometimes considerable disagreement over pressure drop among programs when equal duct sizes and velocities were specified. For example, Carrier and Elite selected a 9-in.-diameter duct and velocity of 679 fpm for Section 6, but the predicted pressure drops calculated by the two programs were 0.14 and 0.02 in. of water, respectively. The pressure drops vary more than the duct sizes because of the dependence of pressure drop on the losses from friction, fittings, and elbows. Each different material type, fitting, and elbow has an associated loss coefficient. Since the programs do not have identical fittings in their libraries, each program will calculate a slightly different loss for a given fitting. This fact does not explain variations of the size noted, however. The designer's experience would be needed to make appropriate adjustments in any duct-sizing program application.

Table 4 displays the results for the same configuration using the static regain method. Duct sizes are calculated using static regain in high-velocity situations, so the initial velocity and the CFM were increased to give more plausible results.

Duct sizes varied more in this case than in the test using equal friction. One reason is that both Elite and Superduct II use static regain only for trunks. All runouts are sized using equal friction by Elite and constant volume by Superduct II. Carrier, Trane, and MC2 use static regain throughout the system. Carrier and Trane gave very similar results for the runouts, with most of Trane's trunk sizes running larger than the others'. MC2's results were very close to Elite's. Superduct II sizes followed the pattern of Carrier and Trane, but with consistently larger runouts.

5 SUMMARY OF RESULTS

With respect to input, the assumed level of user experience varied greatly among programs. Software that assumed high user competence offered more flexibility, but placed more responsibility on the user. The more user-friendly programs tend to limit choices. The designer should be aware of these trade-offs when selecting a program.

Output reports generally contain enough information, but some are formatted so as to be much more readable than others. Because input flexibility and report clarity do not coexist in all programs, potential users must give careful consideration to trade-offs between them.

Documentation ranges from very helpful to marginally helpful. Poor documentation may actually contribute to misuse of a program. Software buyers should attempt to determine the quality and completeness of documentation to the greatest extent possible. If the documents are not available for inspection, comments from other users may be helpful.

Generally, the surveyed companies were very willing to provide customer support and training. However, the basis on which customer help is offered varies among companies. While some have formal support arrangements with customers, others simply give the user their telephone number.

Trial air-conditioning load calculations indicated a good consensus on heating load, with somewhat less agreement on cooling load. Variation in cooling load estimates is clearly linked to differences in the underlying algorithm. Transfer function methods related to the CLTD/CLF manual procedure consistently predict lower loads than TETD/TA-based methods. Commercial software predicted heating and cooling loads comparable to *ASHRAE Handbook of Fundamentals* estimates.

Duct-sizing software generated a wider range of results than did the load programs in spite of the fact that nominally equivalent algorithms were used. Differences in duct size between programs varied in a consistent way in most cases. Calculated pressure drops, however, often appeared disturbingly random. The sources of diversity in these programs are largely submerged within the code and cannot be ascertained on the basis of this study.

No single program package was identified as being clearly the best. Each program has its own unique combination of strengths and weaknesses. The "best" package will vary among the users and applications. The prospective user must assess his/her needs and capabilities to find the most satisfactory program.

6 CONCLUSIONS AND RECOMMENDATIONS

Results of this study indicate that currently available microcomputer-based building loads/energy analysis and HVAC design programs offer a wide variety of options to Corps designers. Specific conclusions about the programs based on the study results are:

1. No single microcomputer program package was clearly superior. Each program package had a unique combination of strengths and weaknesses.

2. Ease of use varied greatly among programs. Amount of input, readability of output, and completeness of documentation varied greatly. Beginning users should consider programs that are easier to use, while more experienced users may wish to consider programs that are more difficult to use, but offer more analysis capability.

3. Vendors of all microcomputer programs tested offer some form of customer support and/or training.

4. Air-conditioning load programs tested on a simple building gave good agreement on heating load predictions and acceptable agreement on cooling load predictions. Predictions were comparable to those obtained by ASHRAE recommended procedures.

5. Differences in algorithms for cooling load produced clear differences in load estimates. As expected, CLTD/CLF-type calculations yielded lower loads than TETD/TA calculations.

6. A variety of industry-approved algorithms is available; therefore, the user's understanding of the particular method used in a program is essential in making safe, intelligent conclusions.

7. Duct design programs generated a rather wide range of results. Pressure drop calculations showed the most diversity. Further study is required to determine the suitability of these programs for Corps designers. Conclusion 6 above applies to these programs even more emphatically.

8. Users should be cautious in their acceptance of vendor-supplied default values which, although convenient, are often inappropriate. Likewise, the impact of the limited modeling detail offered by microcomputer software should be considered carefully. Satisfactory performance of computer tools is largely dependent on the user's understanding of the assumptions they incorporate.

All programs reviewed in this study were found to be suitable for use in performing building loads/energy analysis and HVAC design studies, subject to the above qualifications. It is recommended that designers use this information to select software packages appropriate for their experience levels and design applications.

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